Synopsis

Ph.D. in Physics

A Study of Alpha and Cluster Decay Modes of Heavy and Superheavy Nuclei

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SYNOPSIS

An unstable nucleus reaches stability by emitting any of the particles such as alpha, beta or gamma, which is popularly known as "Radioactivity". Natural radioactivity was discovered by Henri Becquerel in 1896. An alpha particle is the nucleus of helium atom, consisting of two protons and two neutrons. Unstable heavy nuclei with A > 200 generally reaches stable state by emitting an alpha particle. This phenomenon was explained by Gamow and Condon and Gurney independently, via quantum tunnelling and this was one of the earliest applications of quantum mechanics. An exotic mode of radioactivity called cluster decay, a process intermediate between alpha decay and spontaneous fission was well established initially theoretically and later experimentally. The emissions of heavier clusters, such as **^{14}C, ^{24}Ne, ^{28}Mg, ^{23}F, $^{32, 34}$Si** have been established experimentally in trans-lead nuclei decaying into daughters around the doubly magic nucleus ^{208}Pb. Superheavy elements (SHE) usually refer to transactinide elements with Z > 104. Alpha decay is energetically possible and a favored decay mode of such synthesized superheavy nuclei and the decay chain ended with spontaneous fission (SF).

The thesis consists of seven chapters and organized in following manner. Introduction to alpha decay and cluster decay are presented in Chapter 1. An overview of superheavy elements and their synthesis are also discussed. Theoretical models on alpha decay of the superheavy elements are analyzed. An overview of the models used to study alpha and cluster decay is presented in Chapter 1. It also presents the experimental techniques and methods used to determine half-lives of alpha and cluster decay. The objectives and the organization of the thesis are presented at the end of this Chapter 1. Review on both experimental and theoretical works of the decay modes are discussed in Chapter 2. Review on synthesis of superheavy elements with atomic numbers Z = 104 - 118 in cold-fusion reactions are discussed. Discussion on theoretical models dealing alpha and cluster decay is included in Chapter 2.

Chapter 3 explains the methodology of the work. Numerous studies have been carried out to obtain half-lives of alpha decay. These studies, generally, are classified under

fission model and cluster model. These models differ in expression for decay constant through preformation probability. Preformation probability, the probability of alpha/cluster being performed as an entity inside the parent nucleus is assumed to be one in Unified Fission Models (UFM). In Preformed Cluster Models (PCM), it has an explicit value which depends on the size of the cluster emitted. Alpha decay is generally studied using UFM, PCM, Numerical super- aymmetric fission model (NSAFM), analytical super-asymmetric fission model (ASAFM) etc.,. Cluster decay is dealt within the frame work of unified fission models without considering whether the cluster is preformed or not, whereas an explicit preformation is considered and it is said to have a significant value, in preformed cluster models (PCMs). In order to describe large-scale collective nuclear motion and obtain the satisfactory experimental data, a unified nuclear potential is developed by generalizing liquid drop model and incorporating phenomological parameter which account for attractive nuclear interaction energy between two separated fragments. The parameter 'a', which is the range of folded Yukawa function, accounts for both short range nuclear force and diffuseness of the surface. This factor is called "surface diffuseness". The present study aims at analyzing the effect of the range of folding function (Surface diffuseness 'a') of Cubic-plus-Yukawa-plus-exponential Model [1, 2] in preformation probability which is calculated using the idea of Poenaru and Greiner [3]. Further the model is used to analyze the complete binary decay of superheavy nucleus ^{294}Og formed in 3n-evaporation channel of the reaction ^{249}Cf + ^{48}Ca. The properties of ground state decay ^{294}Og are analyzed within the framework of Yukawa-plus-exponential potential with third order polynomial for overlapping region for the use of reduced classical hydrodynamical mass and reduced mass. Classical hydrodynamical mass is explained in this Chapter. Cubic-plus-Yukawa-plus-exponential model is discussed in detail in Chapter 3.

The role of range of folding function in Yukawa-plus-exponential model with cubic barrier for overlapping region is studied for alpha decay of heavy and superheavy nuclei. The half-lives of 108 even-even isotopes of heavy nuclei and 68 superheavy nuclei, by using Cubic-plus- Yukawa-plus-exponential potential, are calculated by varying range of folding function between 0.54 and 0.8 fm [4]. The increase in surface diffuseness, increases the overlapping potential and hence decreases the preformation probability. However the area under non-overlapping region is decreased. Combined effect of this increases half-life by

approximately one order in magnitude. Systematic calculations revealed that accuracy in half-lives are better obtained when a = 0.54 fm for heavy nuclei and 0.8 fm for superheavy nuclei. The effect of shell structure in preformation probability and penetration probability is analyzed [5]. The shell closures at N = 126, 152, 162 and 184 in heavy and superheavy nuclei are clearly depicted in the values of preformation probability, penetration probability [5] and hence in half-lives. The standard deviation calculated between the experimental and calculated half-lives, confirmed the range of 'a' for heavy and superheavy nuclei to be 0.54 and 0.80 fm, respectively. The calculations have been extended to predict the half-lives of the isotopes with $118 \leq Z \leq 125$, $278 \leq A \leq 320$ which are not yet synthesized experimentally. Results pertaining to the role of surface diffuseness 'a' in alpha decay characteristics of heavy and superheavy nuclei are discussed in Chapter 4.

Within the framework of Yukawa-plus exponential potential with third-order polynomial potential for the overlapping region, preference for clusters and heavy fragments as competing decay modes for alpha decay of compound nucleus ^{294}Og formed in 3n-evaporation heavy-ion fusion reaction ^{249}Cf + ^{48}Ca is analyzed [6]. Classical hydrodynamical mass is the transfer mass which considers the radial flow in 'η' motion. Preformation probability values for complete binary decay of ^{294}Og are calculated using reduced hydrodynamical mass for different values of the parameter α_0 and reduced mass. Near symmetric and near asymmetric fragments with magic numbers are found to be highly preferred, when compared to alpha particle for the use of reduced hydrodynamical mass. However, alpha particle is found to have highest preformation probability when compared to other fragments when reduced mass is used in preformation probability. Half-lives calculated for the use of reduced mass result in high order in magnitude, whereas for the use of reduced hydrodynamical mass, they resulted in lowest values of the order of 10^{-16} s. Though classical hydrodynamical mass has large magnitude of mass when compared to reduced mass, use of normalized preformation values gives lowest value of half-lives for symmetric and near symmetric, asymmetric fragments. Fragments with magic numbers such as ^{158}Gd + ^{136}Xe, ^{208}Pb + ^{86}Kr are found to have higher preference. Influence of the parameter α_0 of classical hydrodynamical mass is studied in preformation values. Half-life calculated for alpha decay matches well with experimental value for the use of reduced mass. The results of the study are detailed out in Chapter 5.

Chapter 6 describes the influence of range of surface diffuseness 'a' of Yukawa-plus-exponential potential in experimentally identified cluster decay of heavy nuclei. Further, its dependence on neutron excess of the parent nucleus has been studied. For the experimentally identified cluster emitters, systematic calculations for values of 'a' between 0.54 fm and 0.8 fm have been carried out. The results suggest that as 'a' increases, the nuclear interaction potential widens and deepens which subsequently influences the total potential. The study shows the dependence of surface diffuseness on neutron excess of isotopes of a parent nucleus. It is noticed that for a particular emitted cluster from among the isotopes of a parent nucleus, as neutron excess increases, the value of a for which better matching noted between experimental and calculated half-lives, decreases. A correlation between the 'a' corresponding to best matching half-lives with experimental ones and the neutron excess of the parent nucleus has been carried out with an appropriate fitting. The influence of this parameter for cluster decay of experimentally identified heavy nuclei and the competing alpha decay is studied [7]. Branching ratio between the emitted clusters in relation to alpha emission has a good agreement with the experimental values. The study is extended to alpha and cluster emission of nuclei with $99 \leq Z \leq 116$ and $252 \leq A \leq 293$. Calculated half-lives are in good agreement with experimental values for alpha decay and the branching ratio is also calculated. The parameter surface diffuseness 'a' has a significant influence in the decay characteristics of alpha and cluster decay of heavy and superheavy nuclei.

The summary of the present work is given in Chapter 7 and the significance and conclusion drawn from the work are explicitly presented along with the future scope for the extension of this work.

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